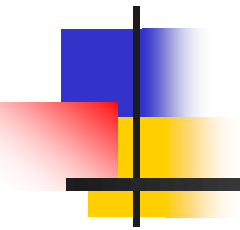
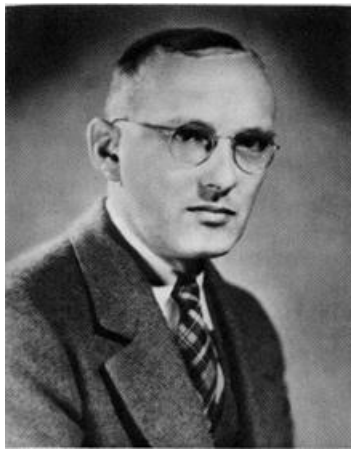


Black Holes II (and Gravitational Waves too)

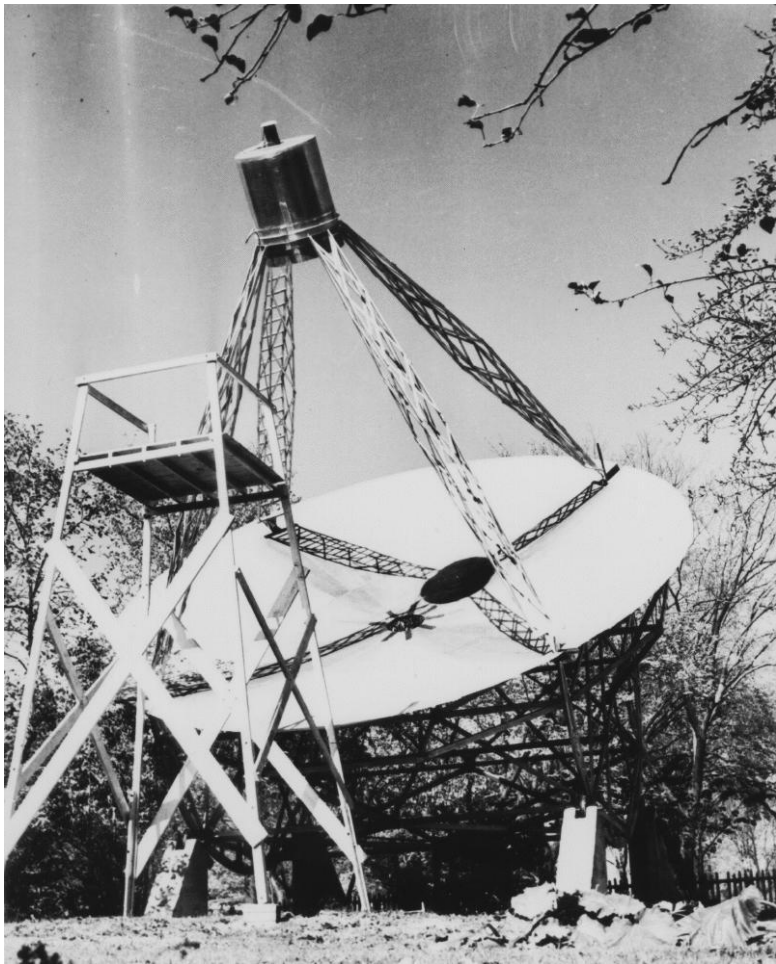
Karl Jansky (1905 – 1950)



- U of Wisconsin undergrad.
- Built a radio antenna on a rotating platform – *"Jansky's merry-go-round"*.
- In 1933 he discovered radio emission from the center of the Milky Way galaxy – he called it ***Sagittarius A*** object.
- He died at the age of 44 – probably, missing the Nobel Prize by only a few years.

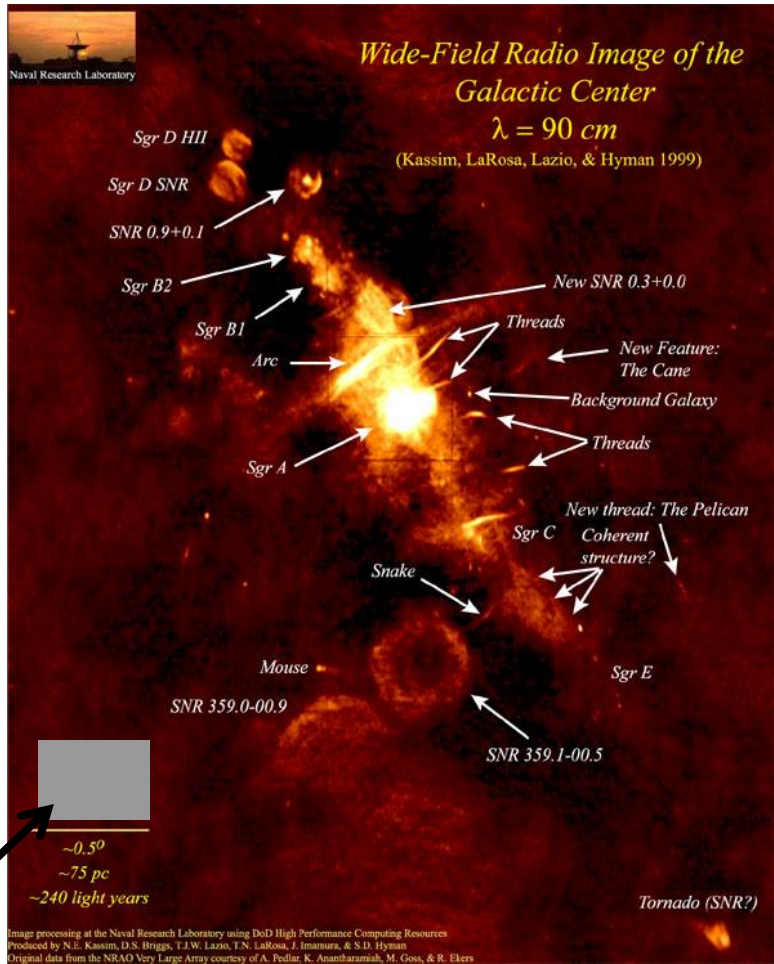
Reber Radio Telescope

- First radio telescope in the world – build by Grote Reber (1911 – 2002) in IL from Karl Jansky's blueprints.
- An astronomical unit of radio brightness – ***Jansky*** is named after Karl.



Center of the Milky Way in Radio

- Sagittarius A (***Sgr A***) object actually consists of 3 different things: an old hyper-nova remnant (Sgr A East), a cloud of gas (Sgr A West), and the true center of our Galaxy: ***Sagittarius A****.



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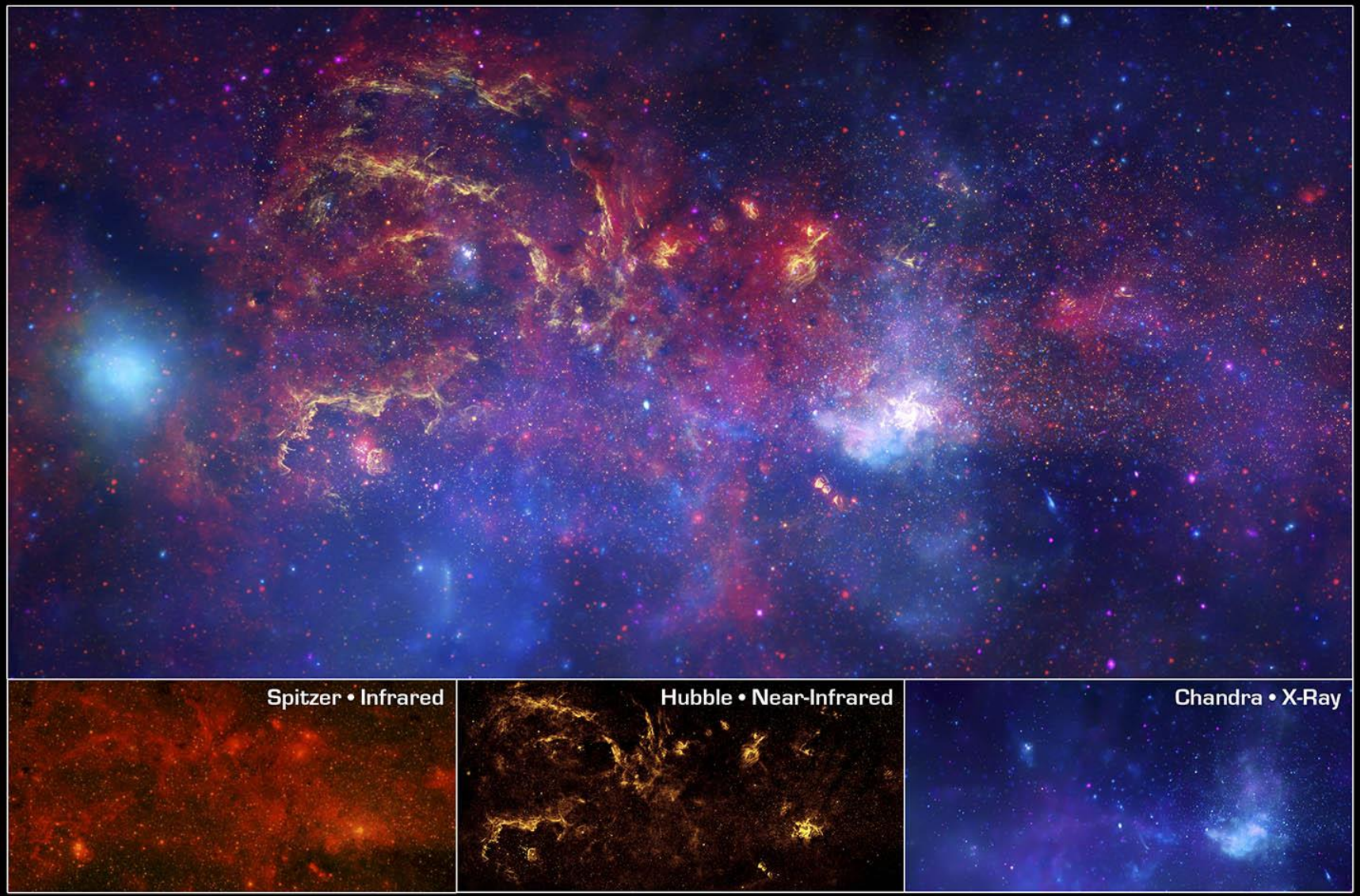


Great Observatories' Unique Views of the Milky Way

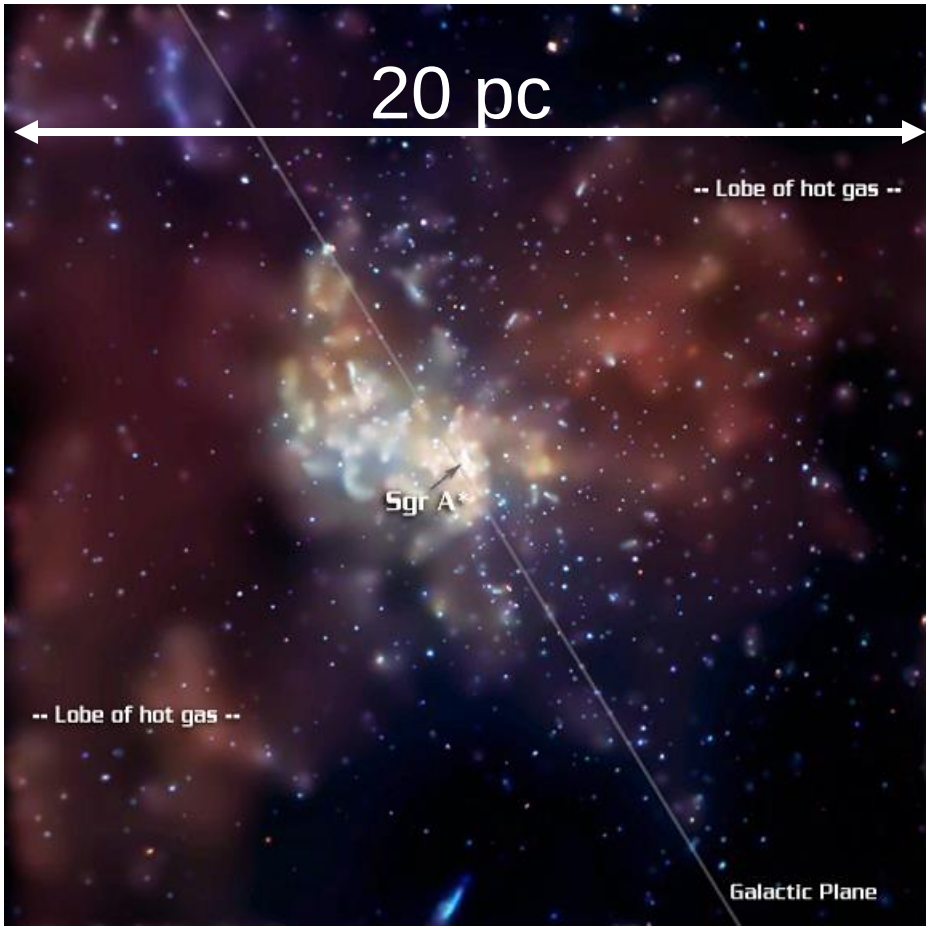
Spitzer Space Telescope • Hubble Space Telescope • Chandra X-Ray Observatory

NASA / JPL-Caltech / ESA / SSC / CXC / STScI

ssc2009-20a

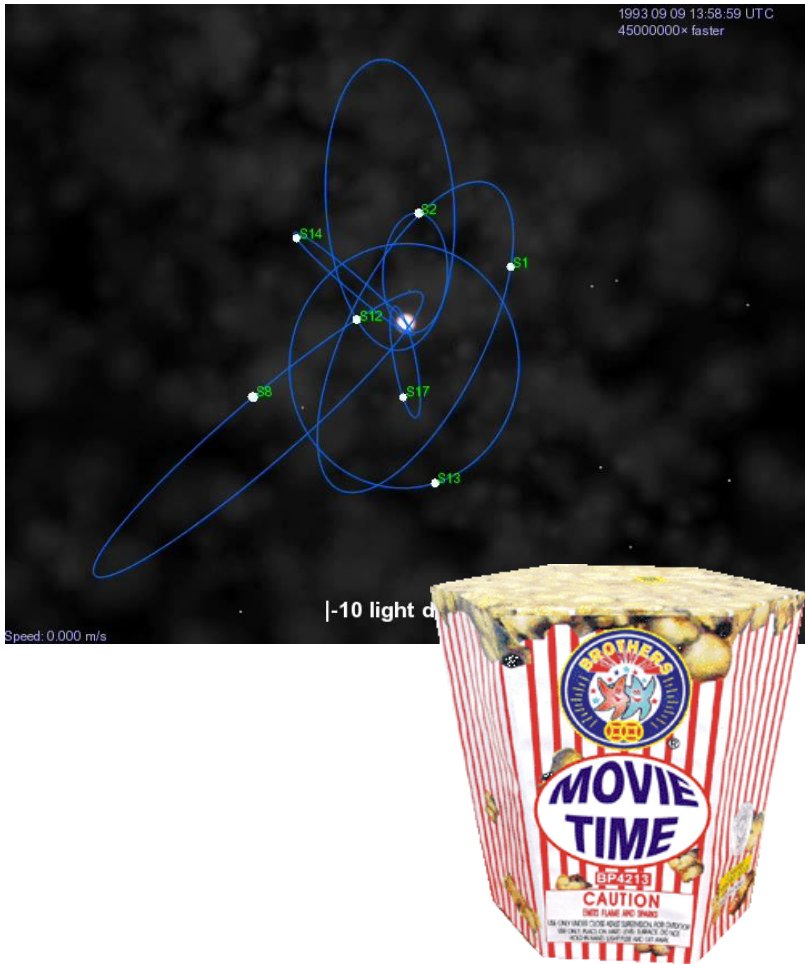
Center of the Milky Way in X-rays

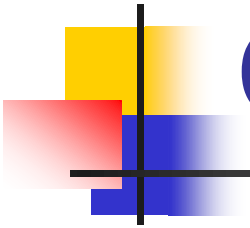
- There is a lot of X-ray activity at the very center of the Milky Way.
- It appears as if Sgr A* is blowing hot gas away from the Galactic plane.



Stellar Orbits Around Sgr A*

- Since 1996, astronomers were tracking orbits of individual stars around Sgr A*.
- Stars move very fast near it – up to 5,000 km/s.





Question

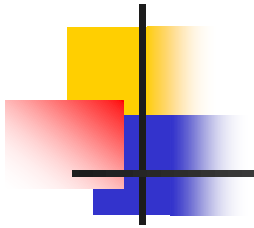
- From the sizes and periods of stellar orbits around Sgr A*, we can determine:
  - **A**: masses of orbiting stars.
  - **B**: mass of Sgr A*.
  - **C**: mass of the Milky Way galaxy.
  - **D**: density of gas at the Milky Way center.
  - **E**: that astronomers have nothing better to do.

Mass of Sagittarius A*

- From stellar orbits, in particularly S2, we can measure the mass of Sgr A* - recall Kepler's third law:

$$G(M_1 + M_2)P^2 = 4\pi^2 R^3$$

- Result: $M_{Sgr\ A^*} = (3.3 \pm 0.7) \times 10^6\ M_\odot$ (3.3 million suns). Rather large for an object less than 0.37AU in radius!



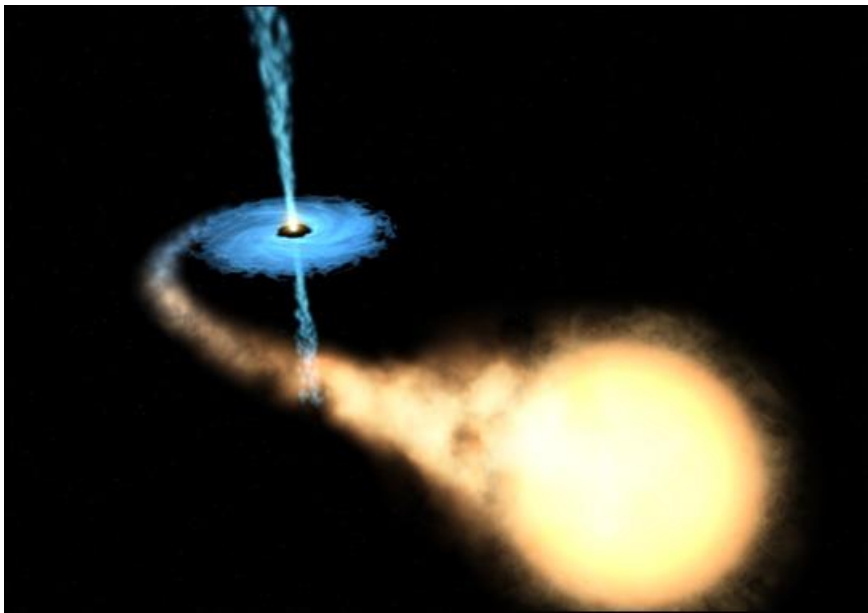
- *Gas is blowing away*
- *In the mid of Milky Way.*
- *Stars whiz by like specs of light,*
- *Hurled by colossal might.*
- *What can take on such a role?*
- *Make a guess – it's a black hole.*

Why Black Holes Are Not Black

- Only very massive stars (above about 30 $M_{\odot}$) end up as black holes.
- Most of these stars form in binary systems. A companion is likely to be less massive – hence, it evolves slower.
- Many stellar mass black holes have Red Giant companions. Can you guess what happens?

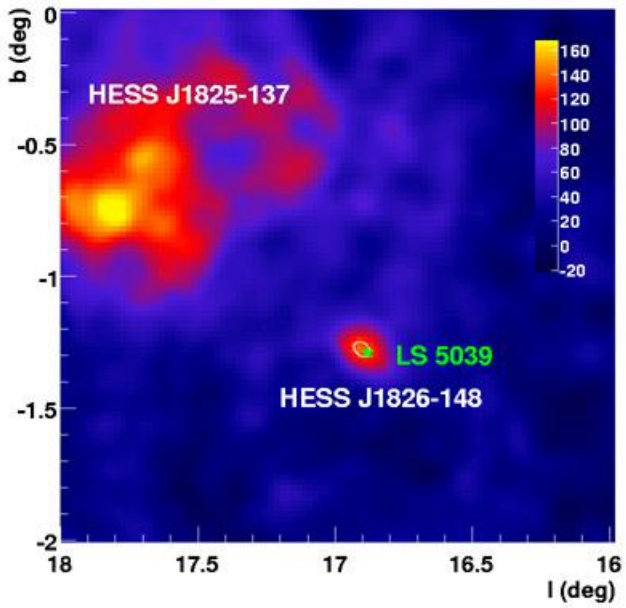
Accreting Black Holes

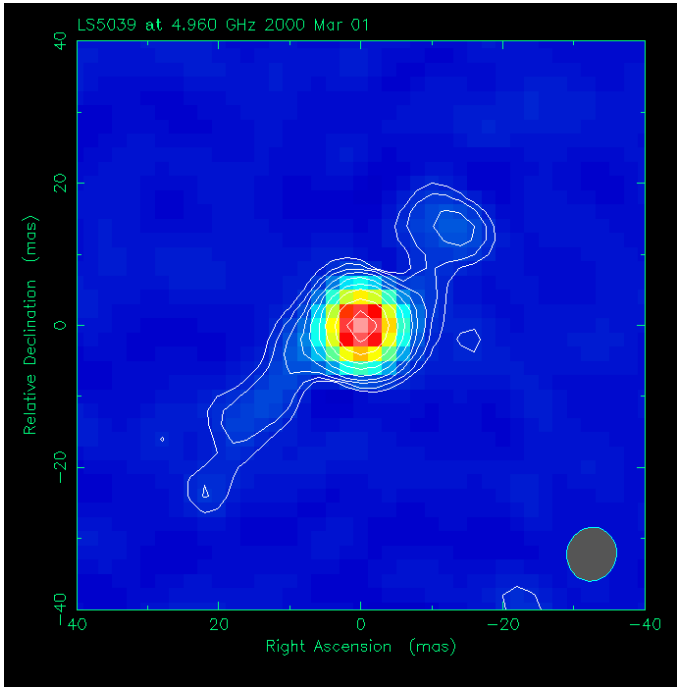
- A black hole in a binary system is likely to accrete gas from the companion. An accretion disk then forms.
- In the inner part of the disk the gas rotates close to the speed of light; friction heats it up to ~100 billion K.
- Would it remain dark?



"Microquasars"

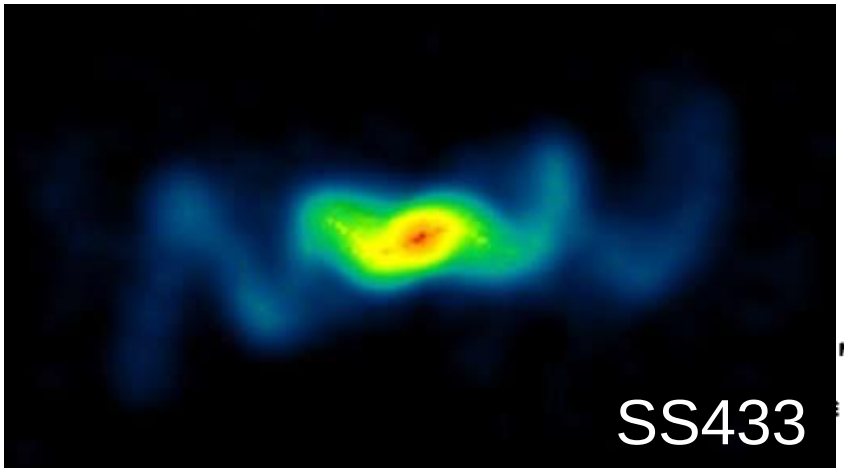
- Such black holes are called ***microquasars***. They are very bright in gamma-rays, X-rays, and also emit in radio.

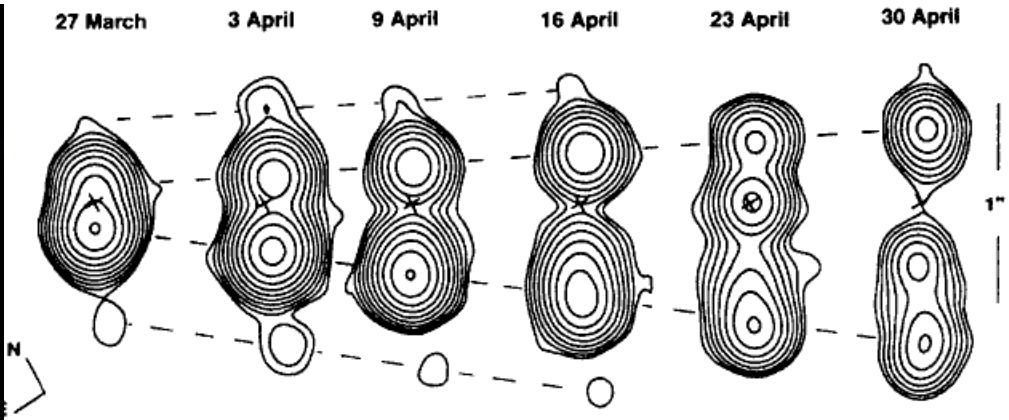




Microquasar Jets

- Many microquasars have jets. The most famous is dubbed SS433 – its jet precesses with a period of 160 days.

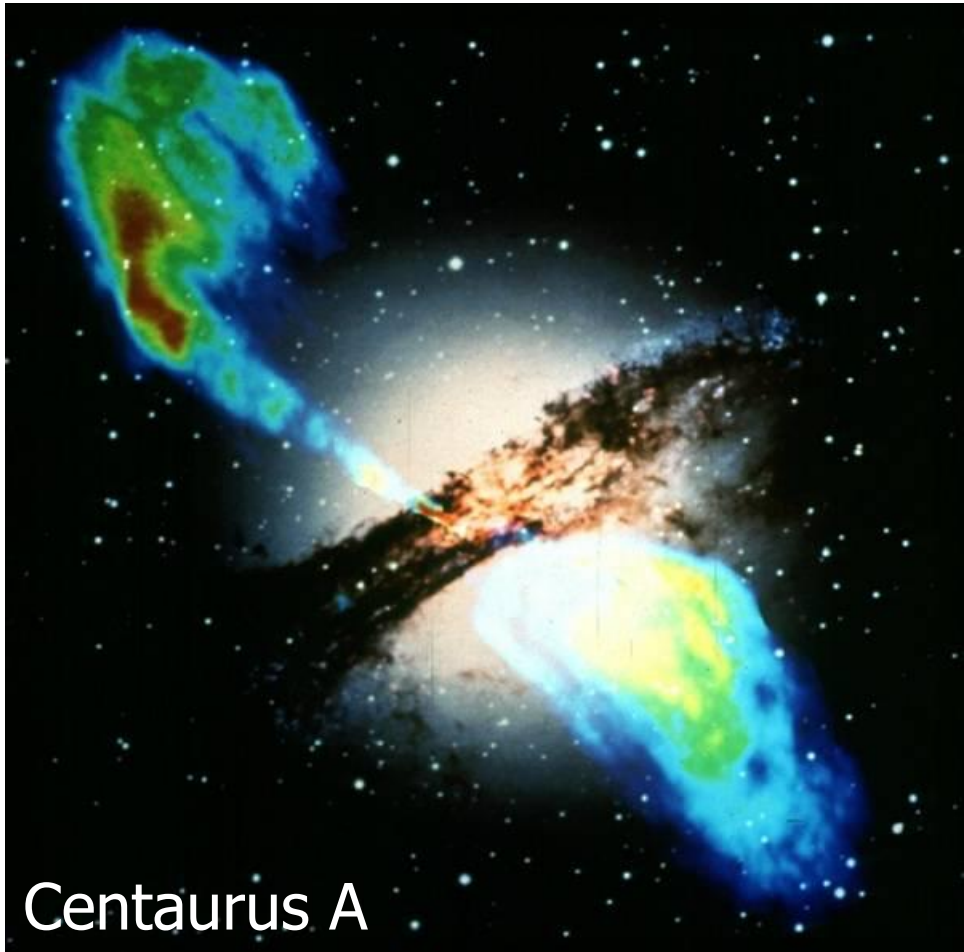




GRS 1915+105: 0.92 c

Active Galactic Nuclei

- Many galaxies have active nuclei, with jets, X-ray and gamma-ray emission.
- Spectral lines show large Doppler shifts, indicating velocities up to 10 - 20% of the speed of light.



Centaurus A

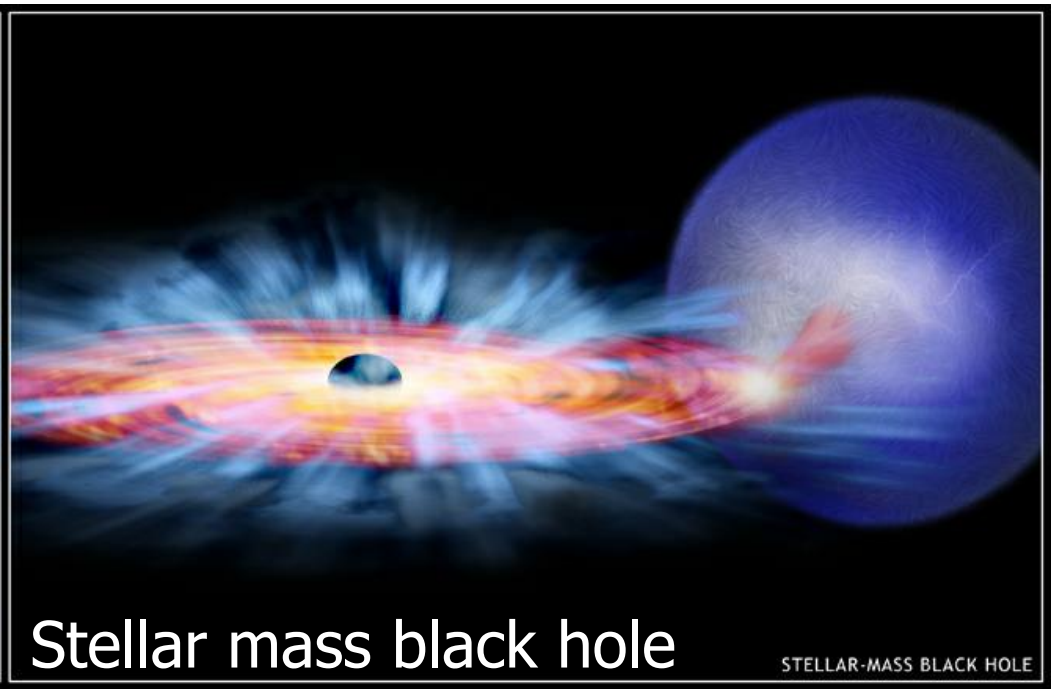
Centaurus A


Visible


The peculiar radio galaxy Centaurus A
Near infrared

Quasars

- There are many types of AGN: DRAGNs, Seyfert galaxies, quasars.
- ***Quasars*** are the most powerful of AGN.

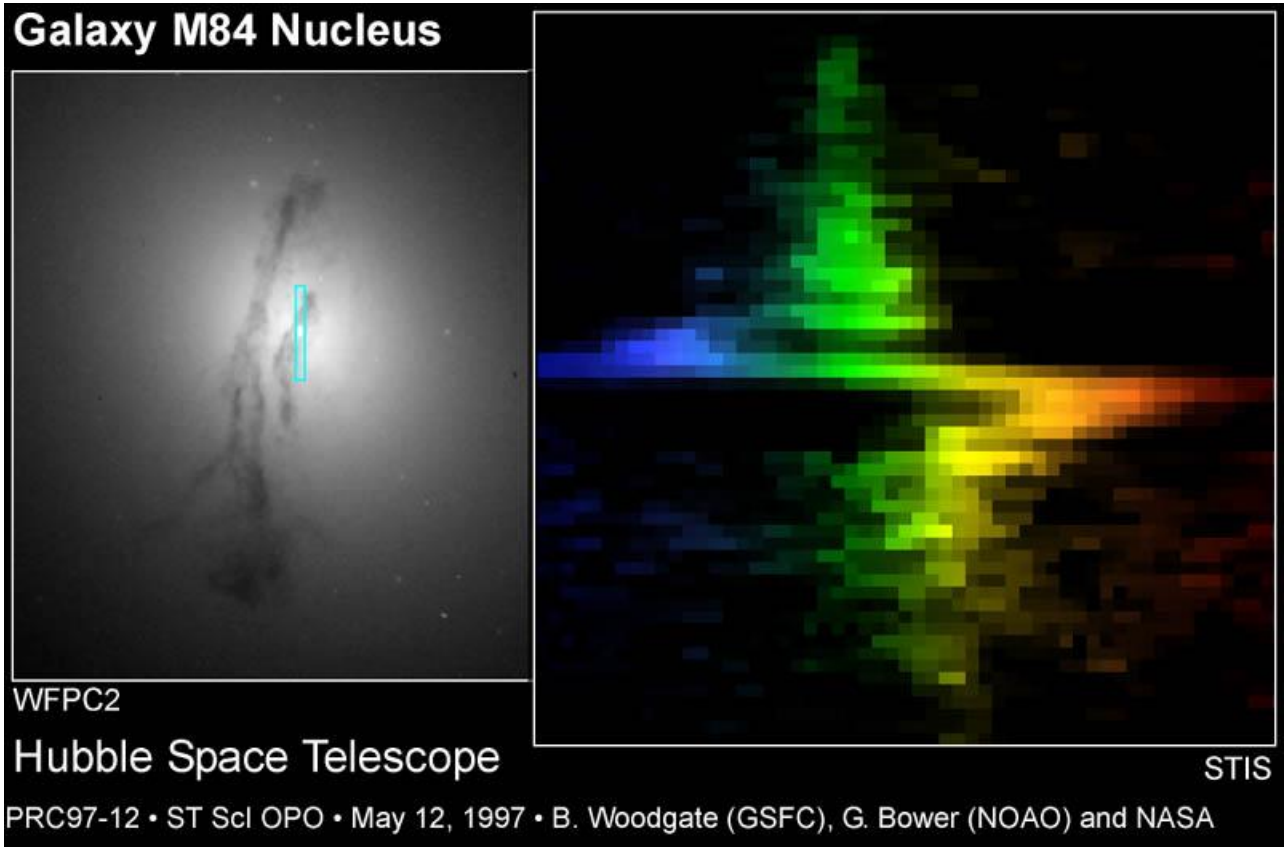


Supermassive Black Holes

- Most large galaxies are believed to have supermassive black holes at their centers (we have found no galaxies without one).
- Largest ones reach 3 billion $M_\odot$ (ours is 3.3 million $M_\odot$, Andromeda's is 20 million $M_\odot$).
- The bigger the galaxy, the larger the black hole. Somehow, galaxies know how big a black hole they must have – this is known as "M-σ" relation.
- But black holes are very small compared to galaxies, there shouldn't be any connection between them. It remains unexplained.

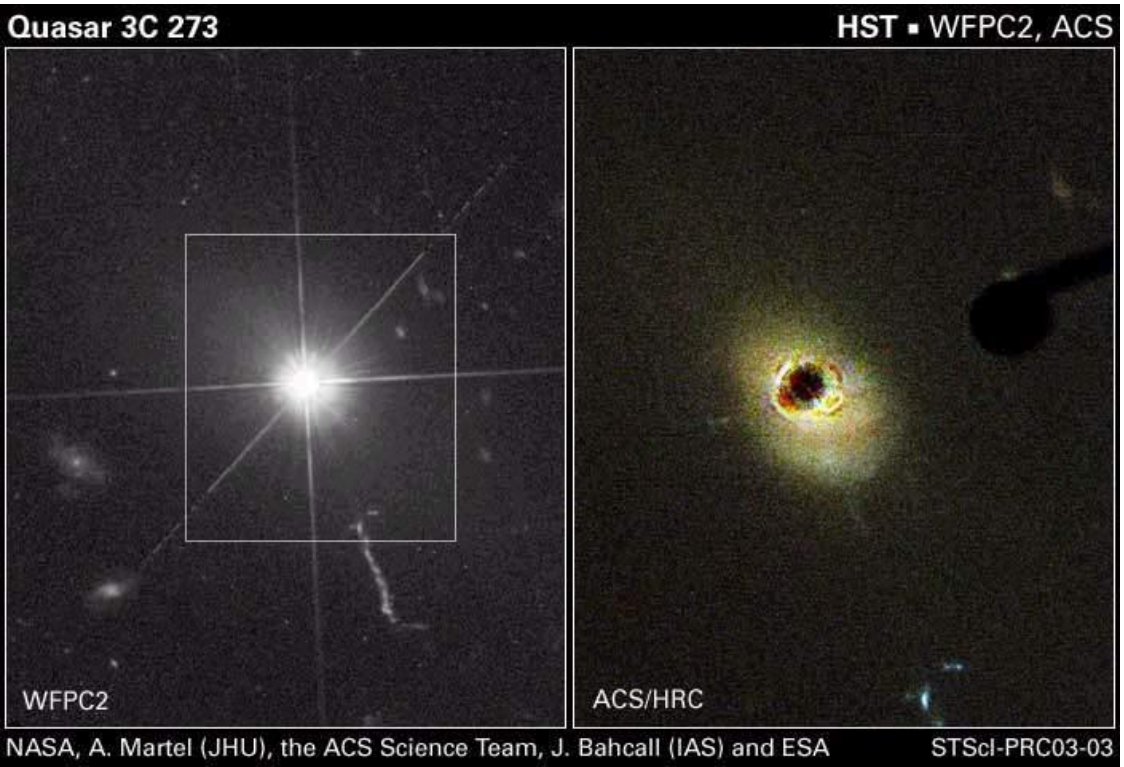
Black Holes Masses

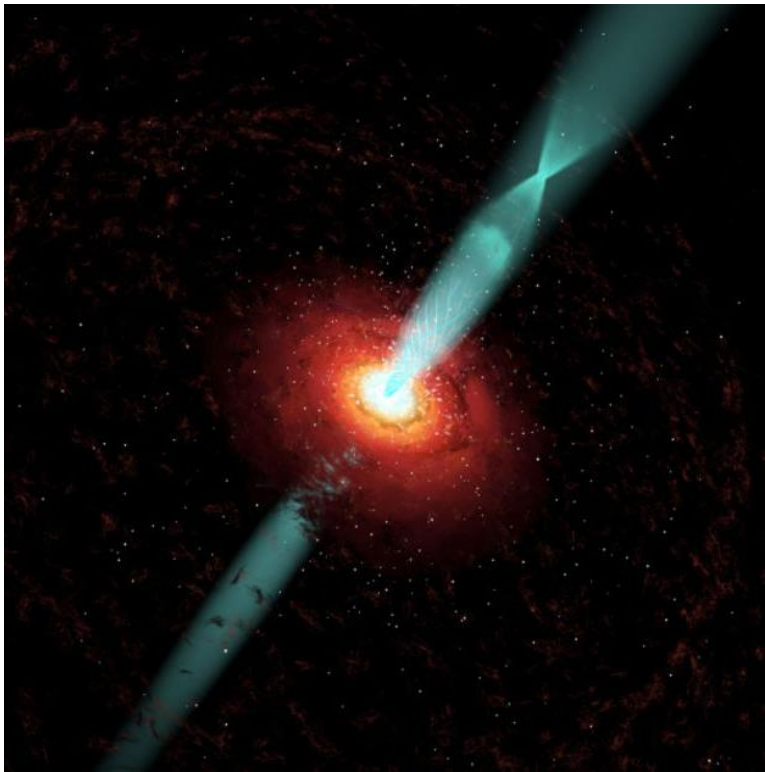
- Black hole masses are measured by the same old Kepler's law.



Believe it or not, black holes are the brightest objects in the universe!

- As gas falls into a black hole, it can turn up to 15% of its rest energy (mc^2) into radiation (stars only do 0.7%, and only in the core).



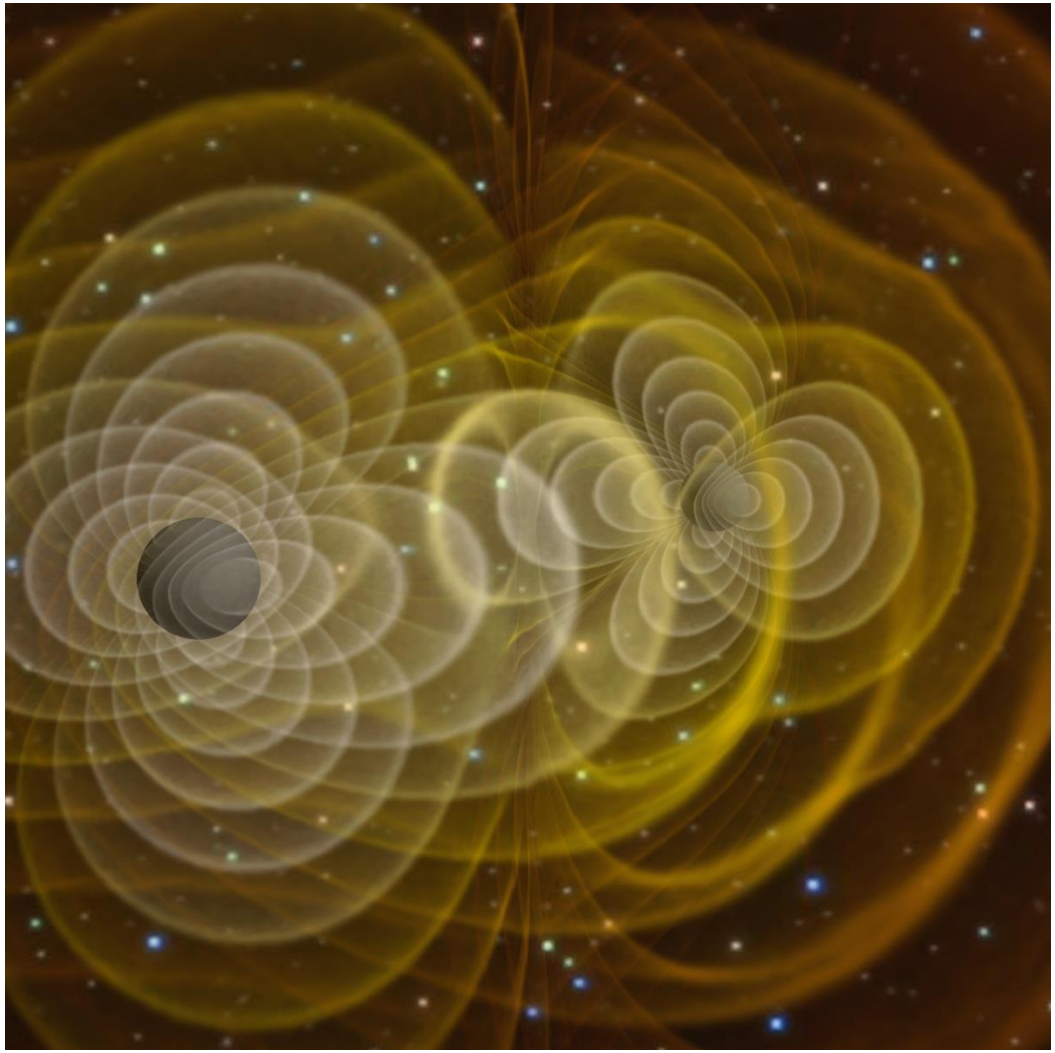


Gravitational Waves

- Most important – don't mix them with *gravity waves*.
- Gravitational waves are ripples of space-time propagating with the speed of light.
- They don't have any analog in Newtonian Mechanics – they are a feature of dynamic space-time.

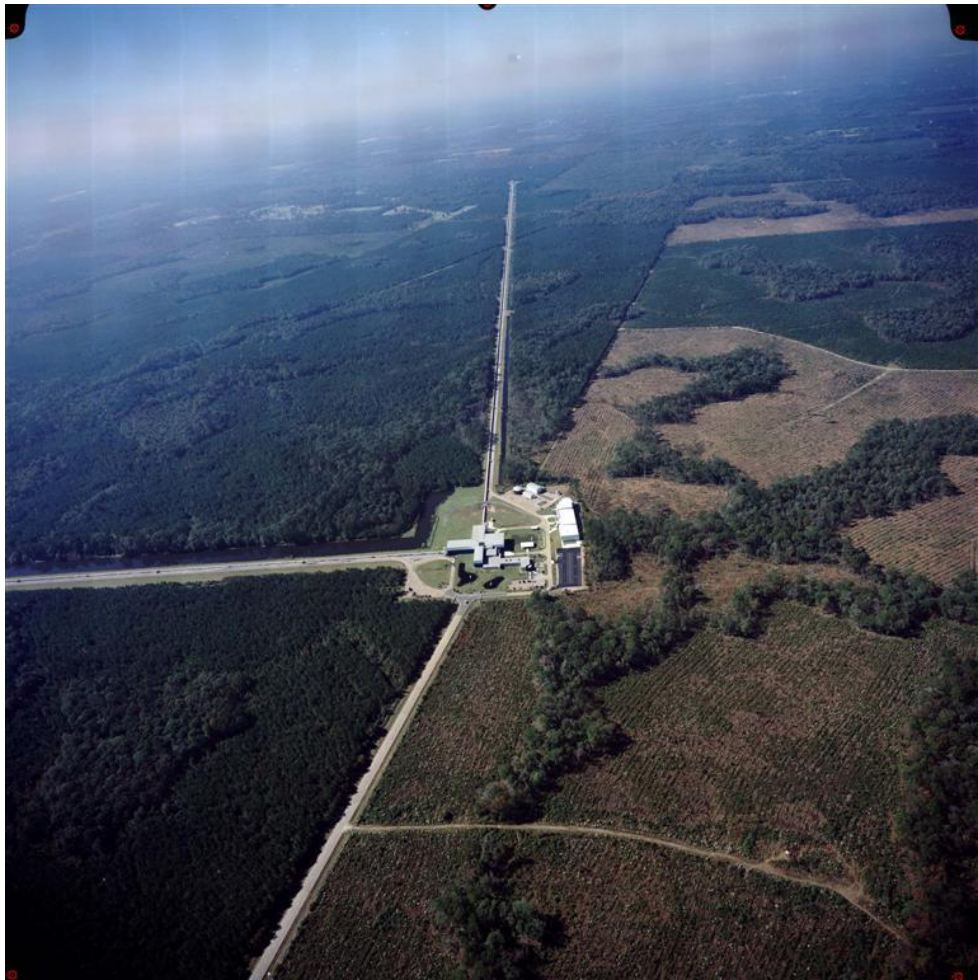
Gravitational Waves

- Gravitational waves are the strongest when two black holes collide and merge.
- None of them have been directly detected yet.



LIGO

- Laser Interferometer Gravitational-wave Observatory has two sites: in Louisiana and in Washington.
- Operational since 2002.
- Since 2010 in a major refurbishing stage.



LISA

- Laser Interferometer Space Antenna is a proposed space mission.
- 3 flying-in-formation satellites 5 million km apart.
- Originally a joint ESA-NASA effort. NASA pulled out in 2011.